U.S. Army Research, Development and Engineering Command

Systems Tradespace Analysis: Assessment of Current Capabilities and Future Directions

TECHNOLOGY DRIVEN. WARFIGHTER FOCUSED.

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NDIA 15th Annual Systems Engineering Conference

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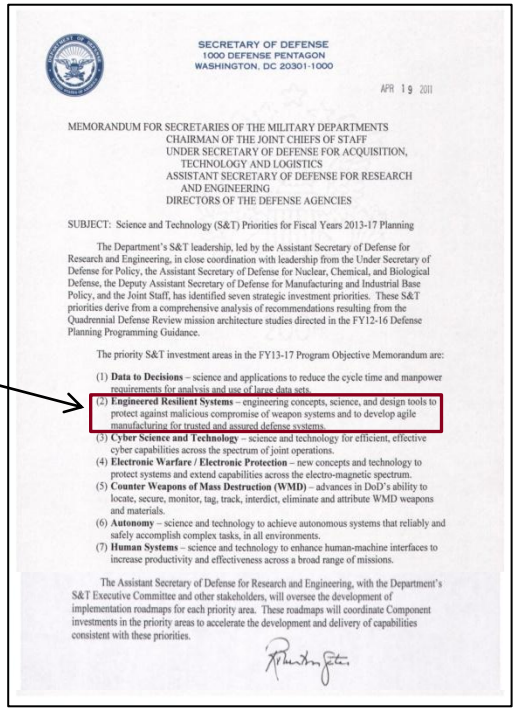
Outline

- Background
- What is an ERS Tradespace?
- Tradespace Exploration Workshop
- Workshop Summary Points
- Tradespace Challenges
- Concluding Thoughts and Recommendations

Background

- ERS = Engineered Resilient Systems
  - Transform system development process
  - Effective, affordable, and adaptable systems
  - Top 7 OSD S&T Priority for FYs 13-17
- Tradespace Analysis Technical Thrust
  - A key technology challenge within ERS
  - Consider more alternatives, longer, across multiple and dynamic futures
  - Current tradespace capabilities fall short
- Tradespace Workshop held July 17-18, 2012
  - Discuss desired capabilities
  - Define gaps to begin prioritizing research



SECRETARY OF DEFENSE
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WASHINGTON, DC 20301-1000

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MEMORANDUM FOR SECRETARIES OF THE MILITARY DEPARTMENTS
CHAIRMAN OF THE JOINT CHIEFS OF STAFF
UNDER SECRETARY OF DEFENSE FOR ACQUISITION, TECHNOLOGY AND LOGISTICS
ASSISTANT SECRETARY OF DEFENSE FOR RESEARCH AND ENGINEERING
DIRECTORS OF THE DEFENSE AGENCIES

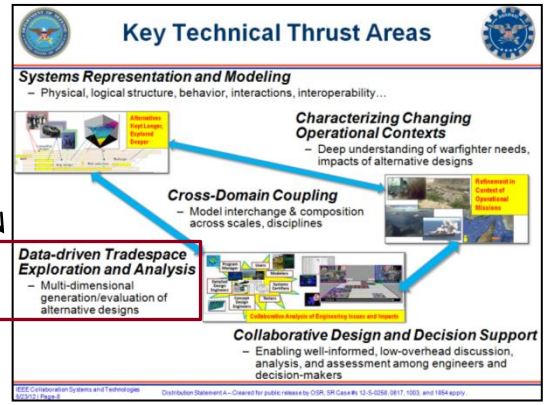
SUBJECT: Science and Technology (S&T) Priorities for Fiscal Years 2013-17 Planning

The Department's S&T leadership, led by the Assistant Secretary of Defense for Research and Engineering, in close coordination with leadership from the Under Secretary of Defense for Policy, the Assistant Secretary of Defense for Nuclear, Chemical, and Biological Defense, the Deputy Assistant Secretary of Defense for Manufacturing and Industrial Base Policy, and the Joint Staff, has identified seven strategic investment priorities. These S&T priorities derive from a comprehensive analysis of recommendations resulting from the Quadrennial Defense Review mission architecture studies directed in the FY12-16 Defense Planning Programming Guidance.

The priority S&T investment areas in the FY13-17 Program Objective Memorandum are:

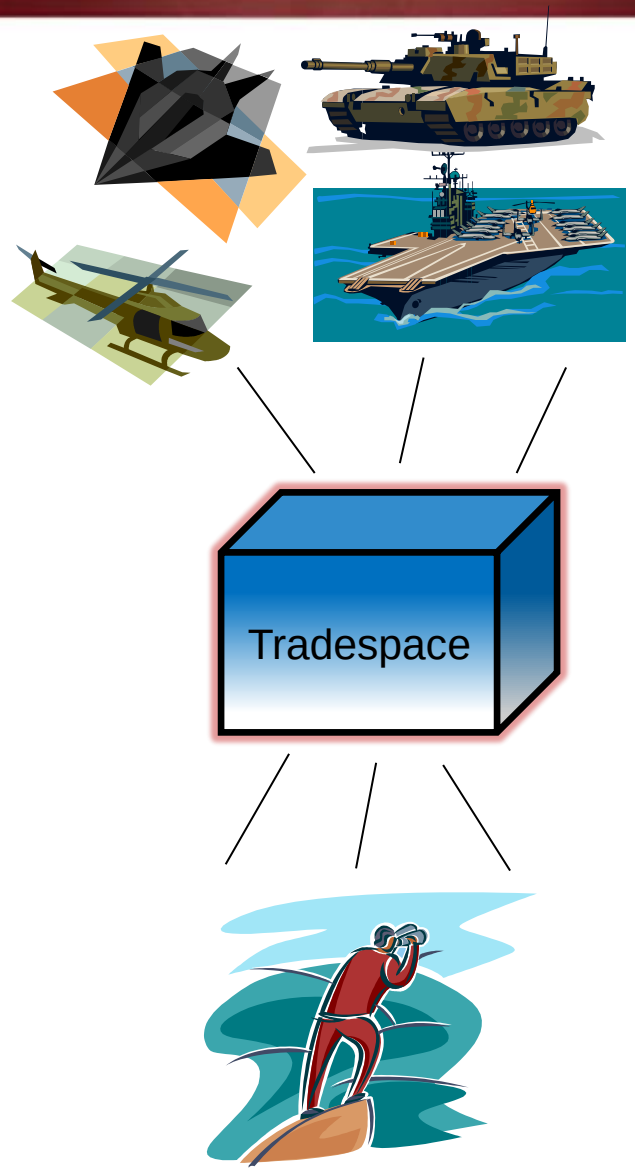
(1) **Data to Decisions** – science and applications to reduce the cycle time and manpower requirements for analysis and use of large data sets.
(2) **Engineered Resilient Systems** – engineering concepts, science, and design tools to protect against malicious compromise of weapon systems and to develop agile manufacturing for trusted and assured defense systems.
(3) **Cyber Science and Technology** – science and technology for efficient, effective cyber capabilities across the spectrum of joint operations.
(4) **Electronic Warfare / Electronic Protection** – new concepts and technology to protect systems and extend capabilities across the electro-magnetic spectrum.
(5) **Counter Weapons of Mass Destruction (WMD)** – advances in DoD's ability to locate, secure, monitor, tag, track, interdict, eliminate and attribute WMD weapons and materials.
(6) **Autonomy** – science and technology to achieve autonomous systems that reliably and safely accomplish complex tasks, in all environments.
(7) **Human Systems** – science and technology to enhance human-machine interfaces to increase productivity and effectiveness across a broad range of missions.

The Assistant Secretary of Defense for Research and Engineering, with the Department's S&T Executive Committee and other stakeholders, will oversee the development of implementation roadmaps for each priority area. These roadmaps will coordinate Component investments in the priority areas to accelerate the development and delivery of capabilities consistent with these priorities.



What Is An ERS Tradespace?

- A highly populated, multi-dimensional, combinatorial design space that cannot be visualized in all dimensions at once
  - More alternatives: generated earlier, kept longer, played out across multiple dynamic futures, while accounting for uncertainties
- Inputs and outputs are disparate, incompletely defined, and dependent, with non-linear relationships
- System behaviors are not predictable, and new behaviors emerge as initial conditions change
- Compromises required when trying to satisfy multiple objectives, from multiple stakeholders with independent perspectives
- Insufficiently explored with current practices



Tradespace Exploration Workshop

- Desired input from tradespace researchers on the challenges of performing tradespace exploration
- Discussed and shared knowledge in tradespace exploration processes, tools, theory, and application
- 40 participants from Academia, Government, Industry
  - Optimization, M&S, data visualization, complex systems, decision making, trade studies
- Held in conjunction with SERC workshop on Tradespace and Affordability; focus was “ilities”.
- Four critical capabilities
  - Broaden, Populate, Manage
  - Link
  - Search, Explore, Analyze
  - Act
- 36 research needs identified; 22 deemed near term (1-3 yrs)

Tradespace Challenge 1: A formal, iterative process wrapped around common decision types

Scenario: Tradespace explorers want to communicate interesting trends, features, and design compromises

Problem Statement: Tradespaces are established and explored ad hoc, contain insufficient or incorrect data for the decisions at hand, and are not navigated with intent to inform key decisions

Current Capability: Tradespace exploration performed informally using data that may not be viable for decision making

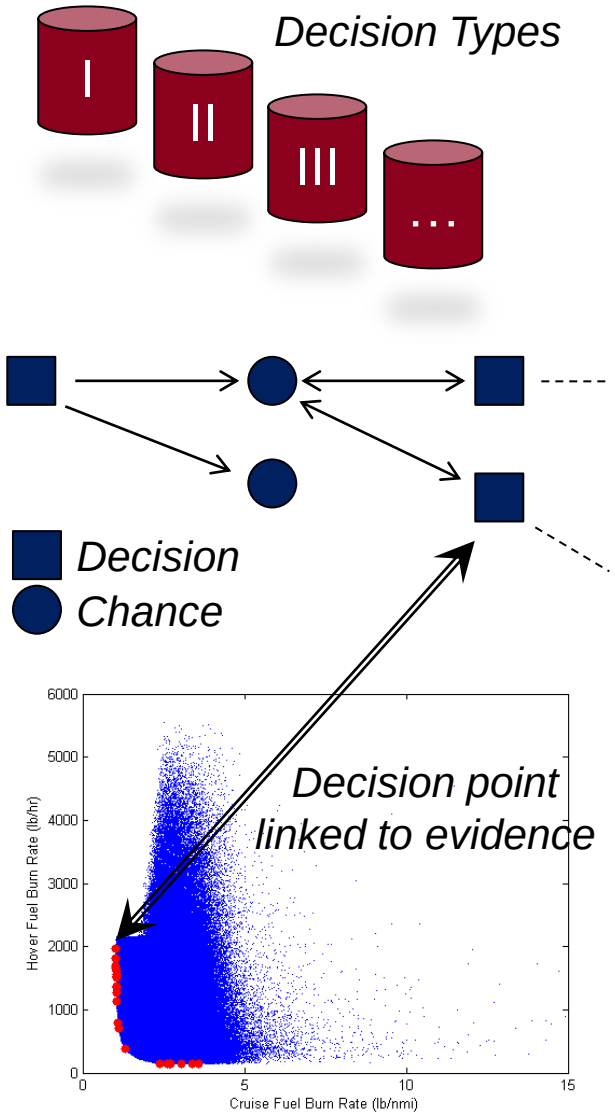
Desired Capability: Formal tradespace exploration process using data required for common decision types, for the purpose of supporting key decisions across the system lifecycle

Near Term Needs:

- Theories to classify types of decisions made by multiple decision makers across system lifecycle and hierarchy
- Knowledge management infrastructure linking decisions to evidence

Out Year Needs:

- Formal process for performing tradespace exploration
- Guidelines for defining necessary and sufficient tradespace exploration



Tradespace Challenge 2: Include non-quantitative factors and "ilities" in the tradespace

Scenario: Decision makers draw conclusions using holistic system views and therefore want qualitative data such as risk, resilience, security, policy, and "ilities" in the tradespace

Problem Statement: Non-technical tradespace entries are difficult to articulate, predict, and scale, and therefore are typically suppressed or even ignored

Current Capability: Qualitative metrics are inconsistently assigned arbitrary ordinal rankings

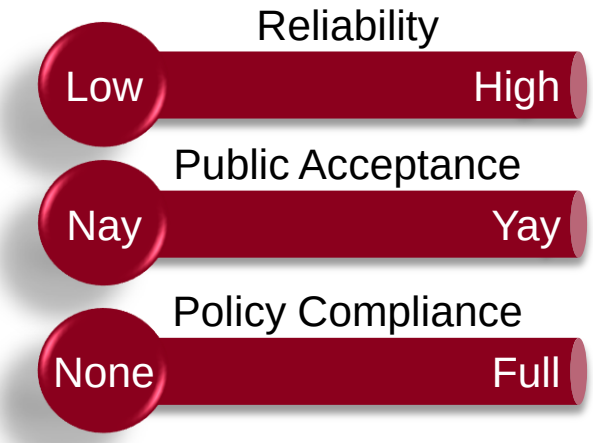
Desired Capability: Early incorporation of qualitative factors in the tradespace, with quantified understanding of their impact on the system

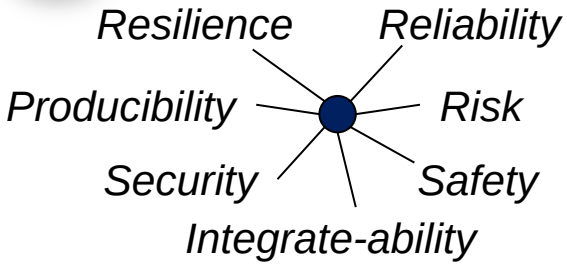
Near Term Needs:

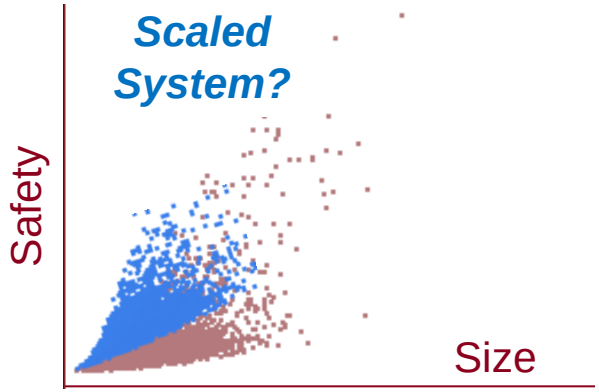
- Standard, formal, composable definitions
- Languages and tools for expressing, analyzing, and evaluating
- Models and relationships that quantitatively determine the impact of "ilities" on each other

Out Year Needs:

- Methods for trading qualitative factors







Tradespace Challenge 3: Dynamic, on-demand, interactive visualization of high dimensional tradespaces

Scenario: Decision makers want real-time, dynamic tradespace engagement while they continually draw conclusions based on knowledge through exploration

Problem Statement: Static tradespaces do not support changing preferences and inquiries, are repopulated slowly, and do not enable trust via interaction

Current Capability: Tradespace snapshots presented upon request, inquiries are posed, tradespaces are supplemented, decision makers are summoned

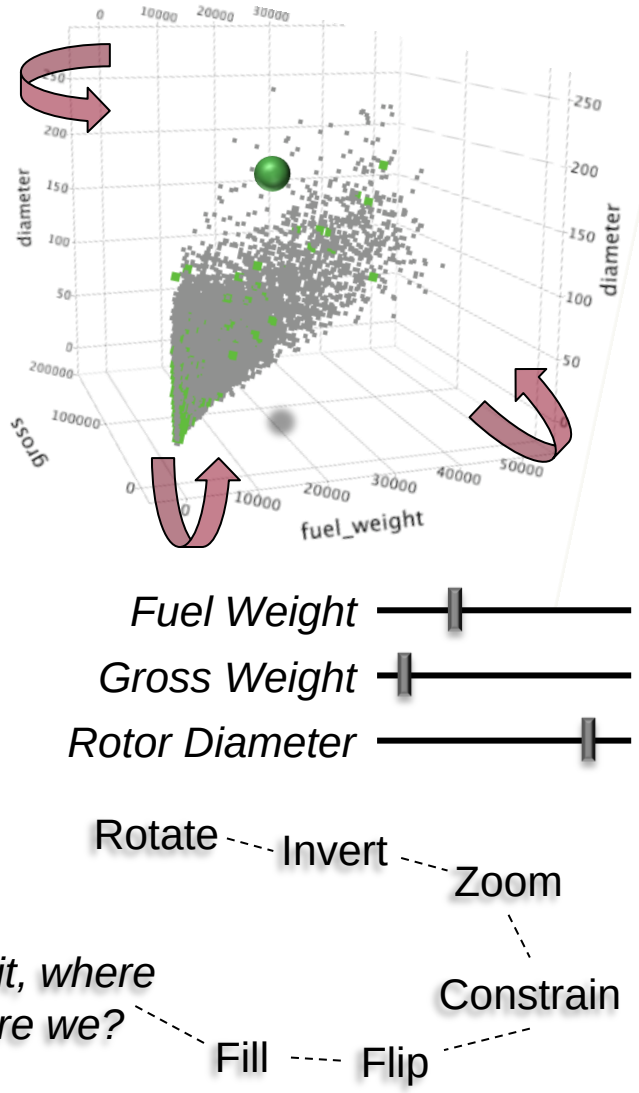
Desired Capability: A distributed, collaborative, real-time visualization environment that promotes trust through interaction with data

Near Term Needs:

- Methods for communicating tradespace conclusions based on preferences and "viewing angles"
- Methods for logging search patterns and decisions

Out Year Needs:

- Normative and prescriptive approaches for interpreting, collapsing, and summarizing multi-dimensional spaces



Tradespace Challenge 4: Conducting and communicating "what if"

Scenario: Decision makers want to extend exploration of existing information into asking "what if" questions and then examine alternative futures

Problem Statement: Explosive growth in design and solution space limits the number of systems and operational contexts that can be explored

Current Capability: Scenarios minimally defined and not representative of future operations, real options, computational scenario planning

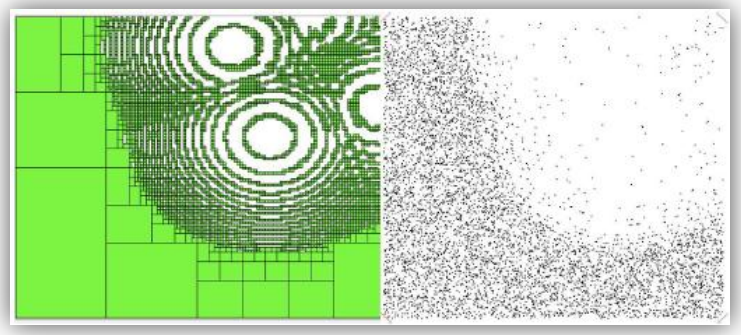
Desired Capability: Generate and evaluate multiple complex systems across multiple, dynamic life cycle futures, while accounting for emergent behaviors

Near Term Needs:

- Methods for classifying, modeling, propagating, and trading uncertainty
- Tools for rapidly assembling rich operational contexts for multiple stakeholders

Out Year Needs:

- Methods and tools for expressing alternative futures via dynamic and interactive visualization



Scenarios: [a, b, c]
Systems: [A, B, C]
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Scenarios: [a, b, c, d, e, f]
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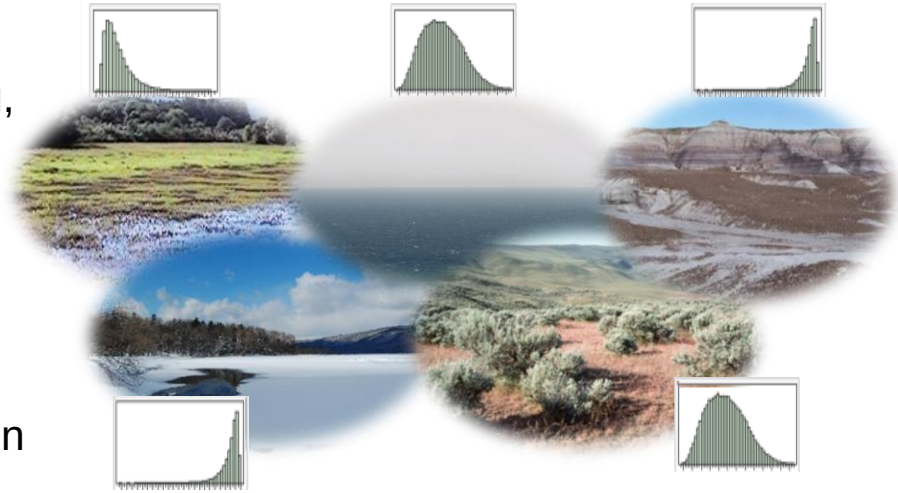


Tradespace Challenge 5: Search, sampling, and feature identification algorithms

Scenario: Human decision makers are presented with large, rich tradespaces from which to draw conclusions

Problem Statement: Decision makers do not know where to look, what to look for, when to look, or how to identify important features in a high-dimensional space

Current Capability: Evolutionary optimization algorithms for multi-objective problems in low-dimensional spaces

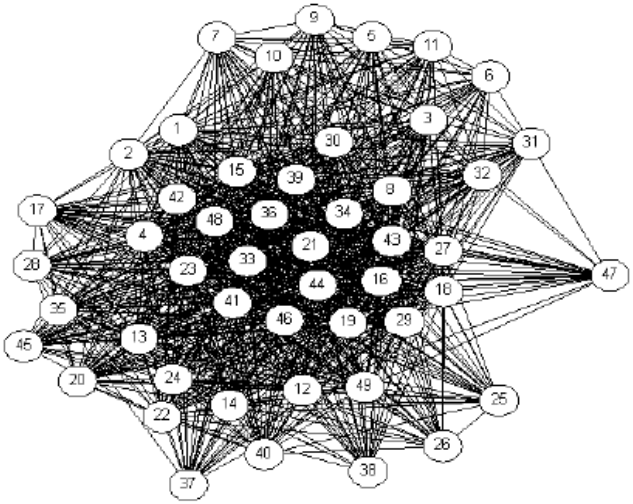
Desired Capability: Identify abstract and previously unknown objectives and constraints in the tradespace using search and classification algorithms

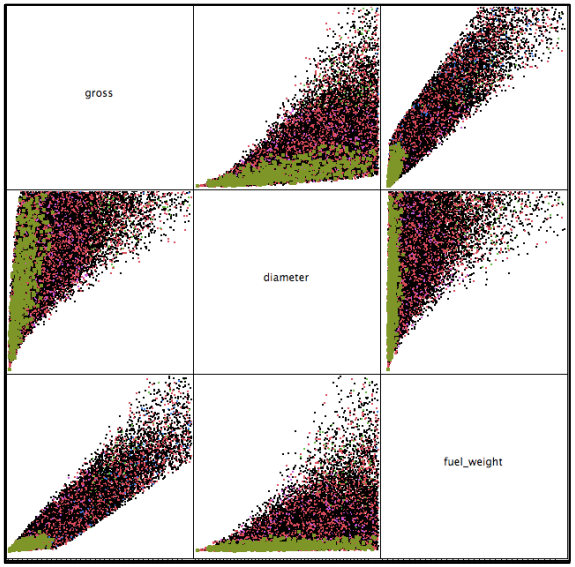
Near Term Needs:

- Effective and efficient search algorithms that can target selective regions
- Methods to apply optimization and machine learning methods to tradespace search

Out Year Needs:

- Approaches to filter and identify “interesting” areas of large tradespaces
- Mechanisms to guide search based on specified dimensions





Tradespace Challenge 6: Consistency, reuse, and retention of tradespace knowledge throughout lifecycle

Scenario: Decision makers want to progressively draw upon earlier tradespace knowledge during system development

Problem Statement: Later phase design decisions are inconsistent, incompatible, or infeasible with earlier decisions due to lack of retention of exploration sequences, decision rationale, and tradespace knowledge

Current Capability: New tradespace studies conducted with new data in each design phase or loosely linked to previous phases through transfer of personnel

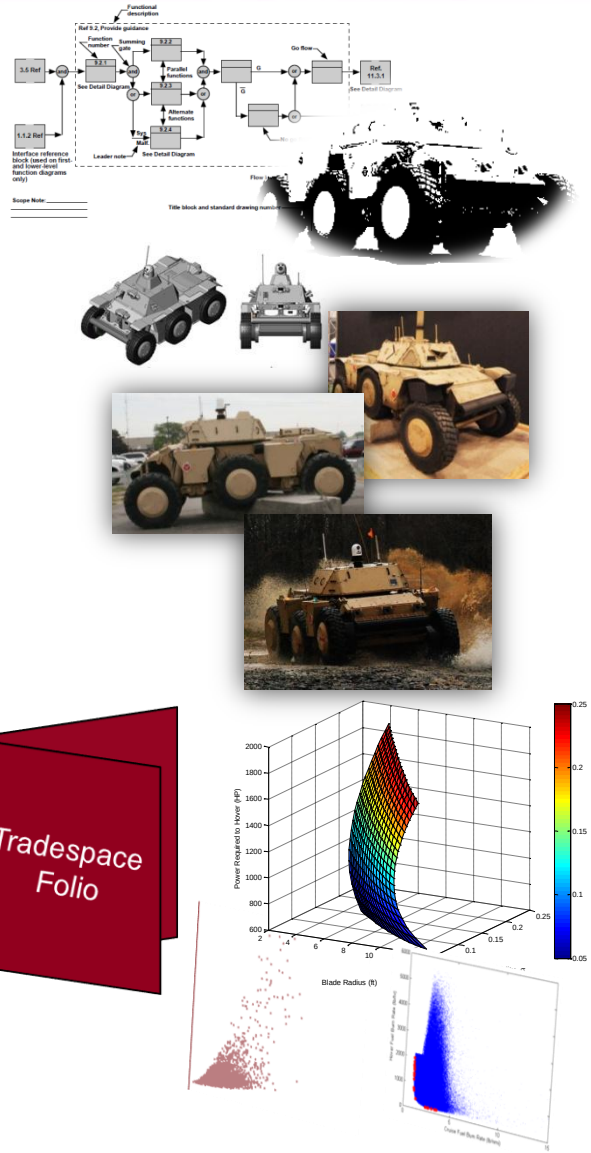
Desired Capability: Persistent tradespace knowledge reused throughout the lifecycle

Near Term Needs:

- Methods for linking decisions: between stakeholders, throughout the lifecycle, and across the system hierarchy
- Empirical/historical based understanding of how decisions made through tradespace exploration have impacted programs

Out Year Needs:

- Methods for evolving the tradespace as information becomes available



Conclusions

- Current tradespace exploration capabilities are insufficient for envisioned ERS tradespace
  - Multiple complex systems across multiple dynamic futures
- Research areas identified that will enable the desired capabilities while addressing problems and challenges
- A tradespace is
  - Functional, perhaps even central to decision making
  - Visual and interactive
  - Dynamic over time
  - More than just a collection of points which each represent a design
- Consider the human aspects
  - Must compellingly communicate tradespace results
  - Social, psychological, and cognitive interaction with data